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NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Washington, D.C. 20007

MOST Project -4

Report 210-H-01

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LEVEL II

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EXPERIMENTAL DETERMINATION OF THE HYDRODYNAMIC LOADING FUNCTIONS FOR THE B-5 TRAILING FAIRING.

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by

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7 TEST AND EVALUATION REPORT,

11 May 1967

12 15p.

14 HML - Report 210-H-01

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INTRODUCTION

The Naval Ship Research and Development Center (NSRDC) is engaged in a broad research program directed toward the development of improved experimental and analytical techniques for predicting the steady-state characteristics of cable-towed systems. The differential equations for describing mathematically the two-dimensional equilibrium configuration and forces of a cable-body system were derived a number of years ago. Solutions for these equations can be obtained numerically using a digital computer[1,2] provided the body characteristics and cable loading functions are known. Usually the characteristics of the towed body can be either calculated or easily obtained using experimental equipment such as the DTMB Planar Motion Mechanism[3] or the Mark 1 Measurement System for Cable-Towed Bodies[4]. However, the cable loading functions are not generally known, and past practice at NSRDC has been to use various loading functions proposed by different investigators[1,5,6]. Some of these functions are based on theory and others are based on limited experimental data; but, in the case of faired towcables, there is considerable doubt as to whether any of the existing functions can accurately represent the hydrodynamic loading on an arbitrary faired towcable.

In view of the aforementioned uncertainties, NSRDC established a project under the Variable Depth Sonar (VDS) Exploratory Development Program to obtain experimentally the two-dimensional steady-state hydrodynamic loading functions of a faired towcable for application to existing and future VDS systems. The experimental approach consisted of towing a rigid faired-cable model in the basin at various speeds, cable angles, and model submergences; and measuring the hydrodynamic forces using the DTMB Cable-Fairing Dynamometer. These data were then used with a curve-fitting computer program to obtain mathematical expressions for the hydrodynamic loading functions.

This report describes the faired-cable model, the towing dynamometer, and the test procedures; gives sample curves of normal and tangential forces versus submergence for various speeds; presents tabulated

[1] References are listed on page 14.

loading functions; gives plots of the normal and tangential loading functions versus cable angle and a plot of drag coefficient versus Reynolds number; and provides the mathematical expressions derived for the loading functions.

DESCRIPTION OF FAIRED-CABLE MODEL

The model consists of a simulated stranded cable, a trailing fairing, and seven equally spaced clips as shown in Figure 1. The simulated cable was geometrically scaled with a linear ratio of 0.175 from a 0.35-inch-diameter double-armored cable[7]. The cable consists of twenty-four 0.219-inch-diameter strands with a 16.45-inch left-hand lay joined to a seamless steel tube. The trailing fairing was scaled geometrically to the proper size using a DTMB B-5 fairing shape[8]. The physical characteristics of the model are given in Table 1.

TABLE 1

Physical Characteristics of the Faired-Cable Model

Length, inches	89.25
Chord, inches	7.75
Cable diameter, inches	2.00
Maximum fairing thickness, inches	1.60
Clip width, inches	0.74
Clip thickness, inches	0.04
Approximate clip spacing, inches	12.0
Ratio of wetted surface area to projected frontal area	8.53

DESCRIPTION OF DYNAMOMETER

The cable-fairing dynamometer is shown in Figure 2 with the faired-cable model attached. The normal force X, lateral force Y, and tangential force Z on the model are sensed by 4-inch-cube modular force gages of the type described in Reference 3. Interchangeable gages with capacities ranging from 50 pounds to 1000 pounds are available so that

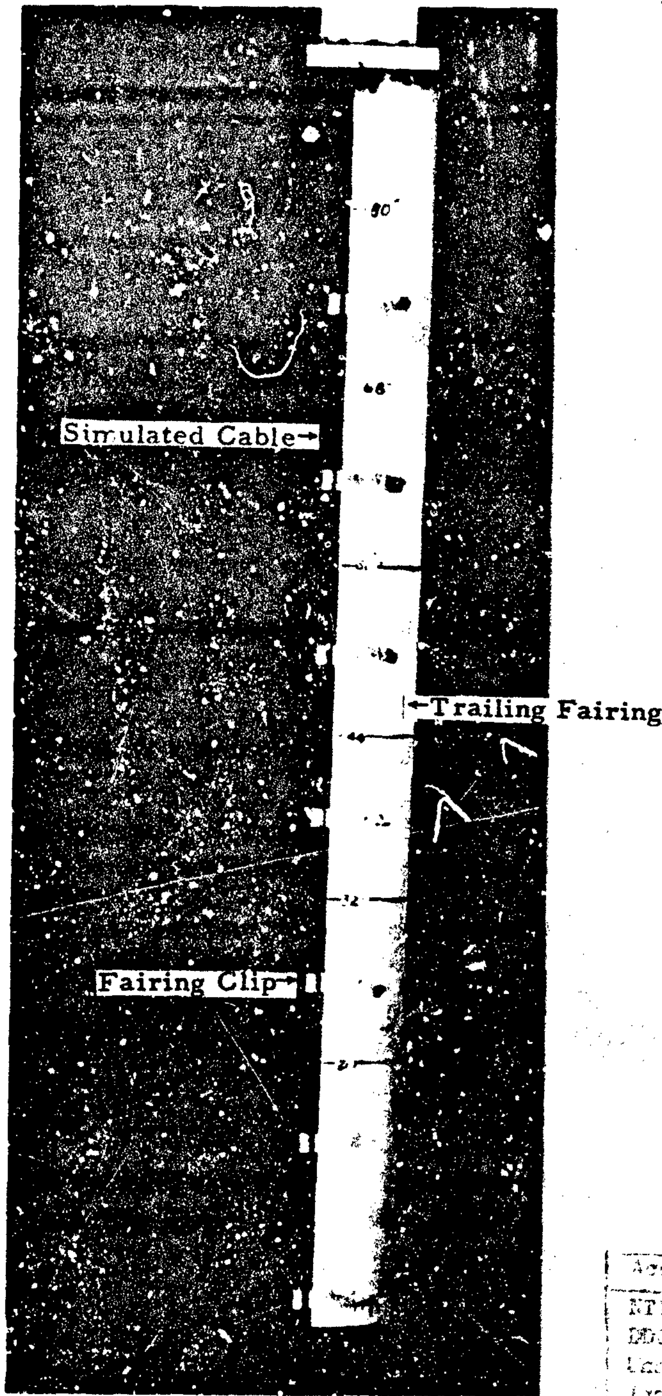

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Figure 1 - Faired-Cable Model

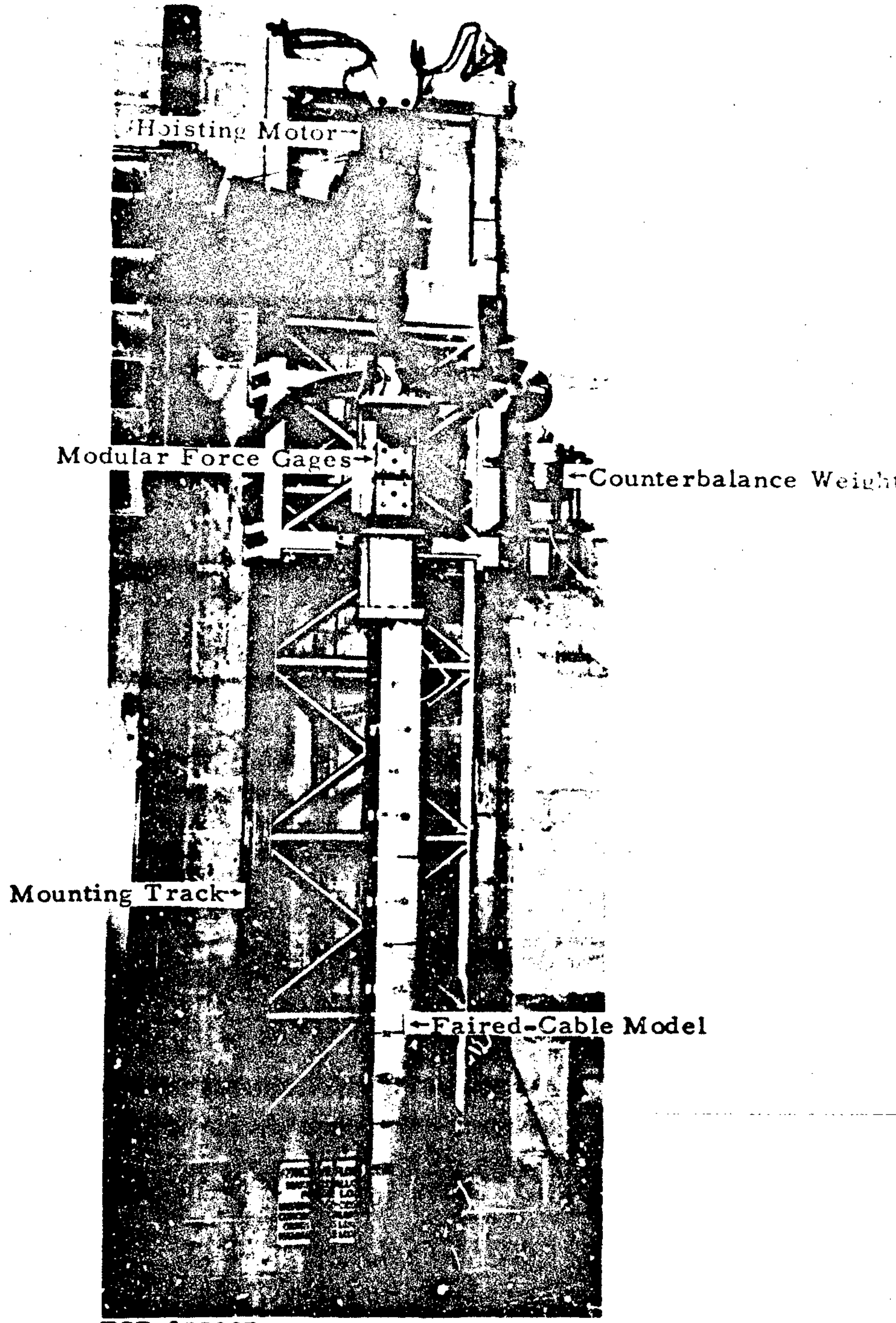

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Figure 2 - Cable-Fairing Dynamometer

high accuracy can be maintained over a range of speeds. However, the dynamometer design limits any of the three component forces to 500 pounds.

The tilt table angle is adjustable so that the cable angle ϕ relative to the free stream may be varied from 90 degrees to 30 degrees in 5-degree increments. The vertical position of the model and tilt table is also adjustable by means of an electric hoist to give model submergences from 0 to about 7 feet. A weight-pan system provides a means of counterbalancing the model weight on the gages at each submergence and cable angle.

The instrumentation used in this test consisted of three modular-gage control units, two integrating digital voltmeters to measure X and Z forces, and a strip-chart recorder to monitor the Y force. The X, Y, and Z forces were measured with 200-pound-capacity, 1000-pound-capacity, and 50-pound-capacity gages, respectively. Carriage speed was measured using a magnetic pick-up and gear wheel with the signal fed to an electronic counter.

TEST PROCEDURES

The model was towed in the high-speed basin at cable angles ranging from 90 to 30 degrees in 5-degree increments. The model submergence was varied from 80 to 32 inches in 12-inch increments at nominal towing speeds of 2, 4, 6, and 8 knots for each cable angle. In addition, for a cable angle of 90 degrees, the model was towed at nominal speeds of 0.75, 1, 1.5, 3, 5, and 7 knots at all submergences. The X, Y, and Z forces and carriage speeds were recorded for all test conditions. The Y-force recording was used mainly as a basis for alining the model with the flow and as a means to monitor the lateral oscillations of the model at test speeds.

HYDRODYNAMIC FORCES

Since the measured forces were generated by a finite surface piercing model, the data contain both end effects and surface effects. The desired

two-dimensional hydrodynamic forces were obtained for each angle investigated by the following analysis. First, the X-force data for each angle and submergence were corrected for variations in speed by plotting them as a function of speed squared. A curve was then faired through each set of data points and the forces at speeds of 2.00, 4.00, 6.00, and 8.00 knots were picked from each faired curve. The faired values for each angle in turn, were plotted as a function of model submergence for each of the even values of speed, as shown typically in Figure 3. In all cases, the X-force was directly proportional to the model submergence, over the range covered in the tests, i.e., the end and surface effects did not vary with submergence. Thus, the two-dimensional normal force per unit length for each angle and speed is the slope, $\frac{\Delta X}{\Delta s}$, of the appropriate curve.

Because of the form of the Z-force versus speed squared curve, the Z-force data were not corrected for speed. The Z-force data were plotted as a function of model submergence for various speeds at a given angle, as shown typically in Figure 4. The two-dimensional tangential force per unit length was then obtained from the slope of the Z-force versus submergence curve.

HYDRODYNAMIC LOADING FUNCTIONS

The hydrodynamic loading functions are defined as the ratio of the steady-state, two-dimensional, hydrodynamic forces acting on an element of cable at an angle ϕ to the free stream to the force acting on the element when it is normal to the free stream (ϕ = 90 degrees). For a given faired cable and given speed, the loading functions are dependent only upon cable angle.

The normal and tangential loading functions are determined using the slopes of the force-submergence curves. The slopes at each angle are divided by the slope of the normal-force curve at an angle of 90 degrees to obtain the loading function values for each speed and angle. These values for the subject tow-cable are tabulated in Table 2. The data for the normal loading function are plotted in Figure 5. Because of the variation in the Z/X_{90} values with speed for a given angle, the values at each angle were averaged, and the average values are plotted in Figure 6.

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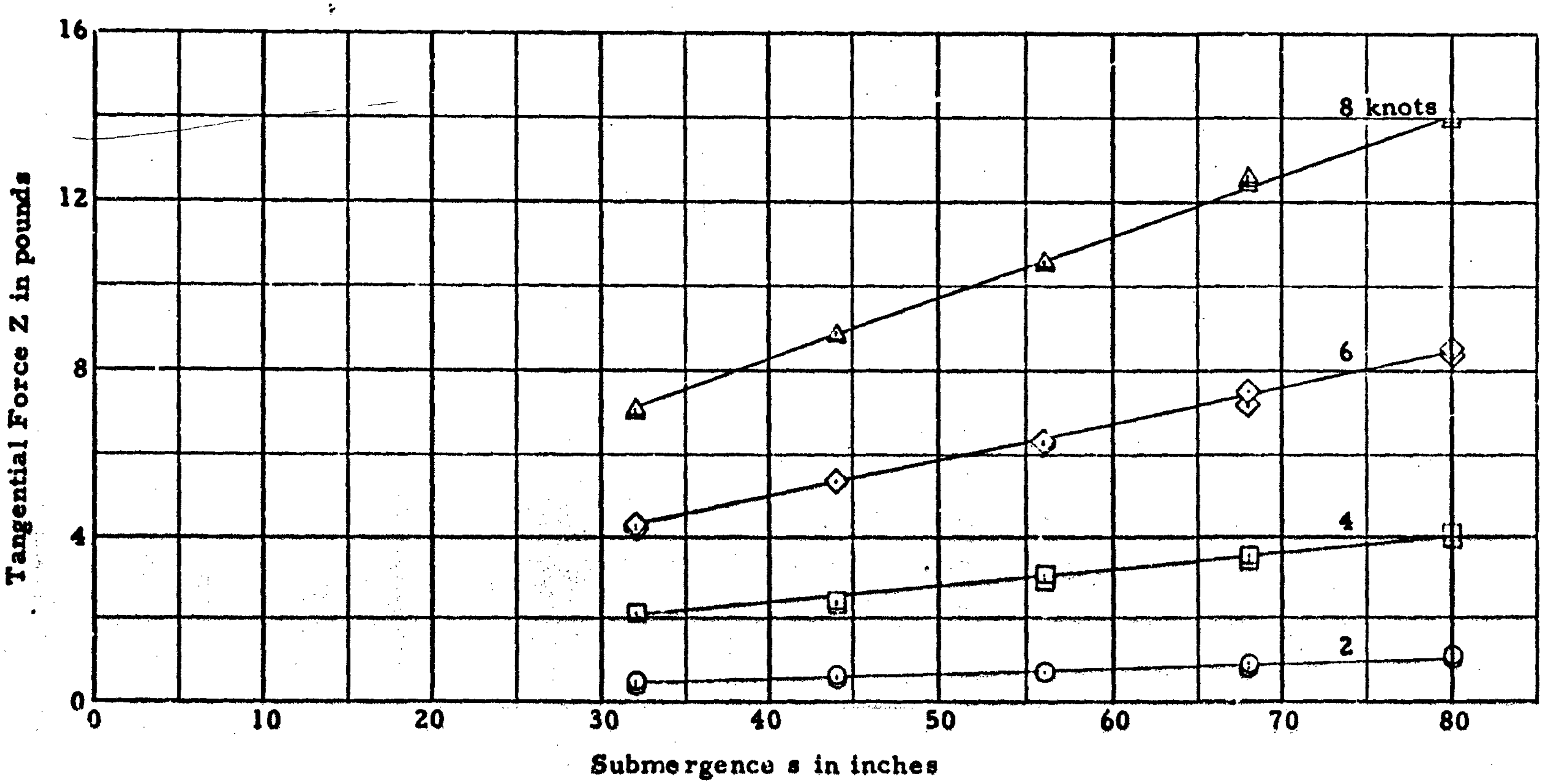

Figure 4 - Tangential Force Versus Submergence for a Cable Angle of 35.30 Degrees

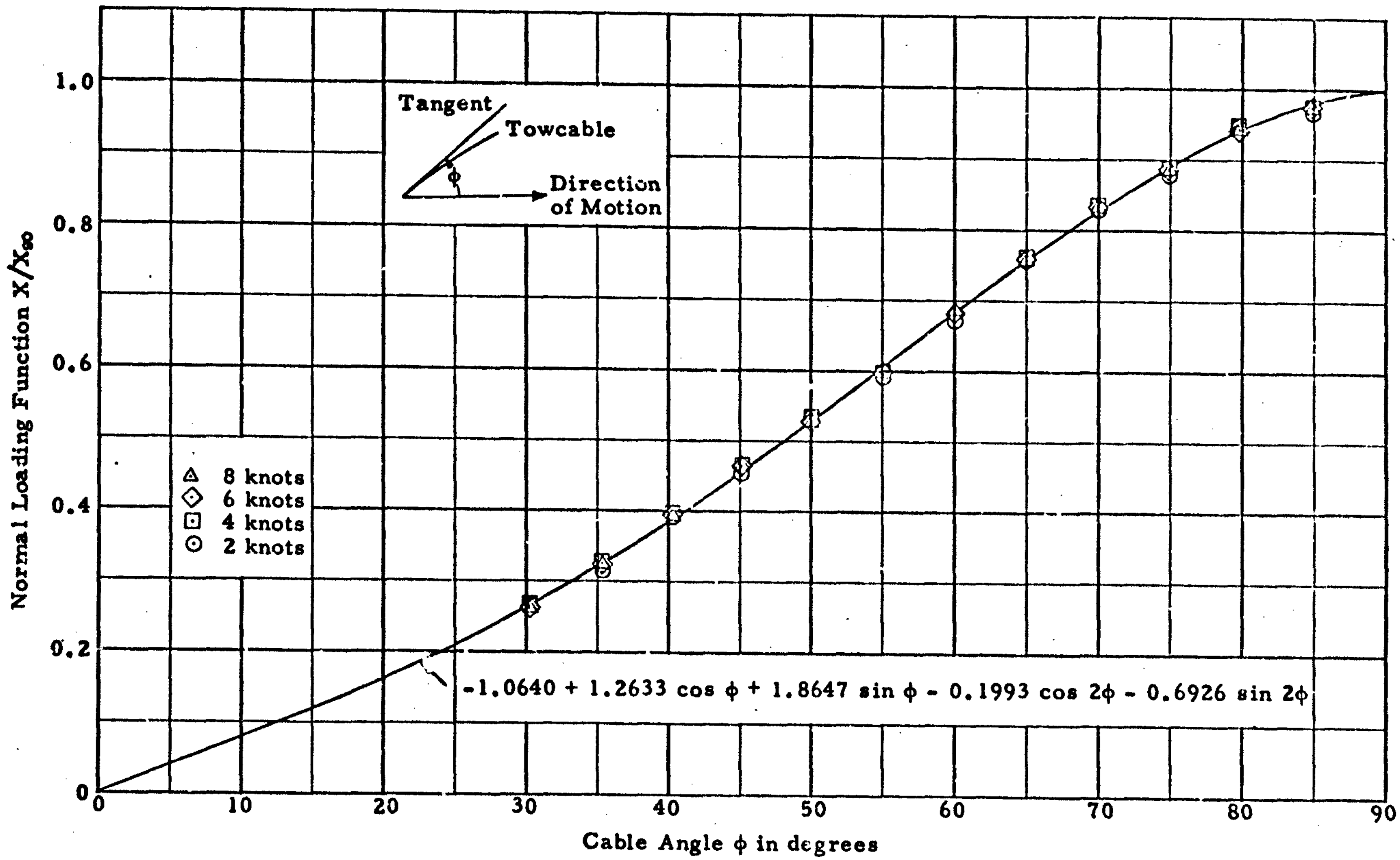

Figure 5 - Normal Loading Function Versus Cable Angle

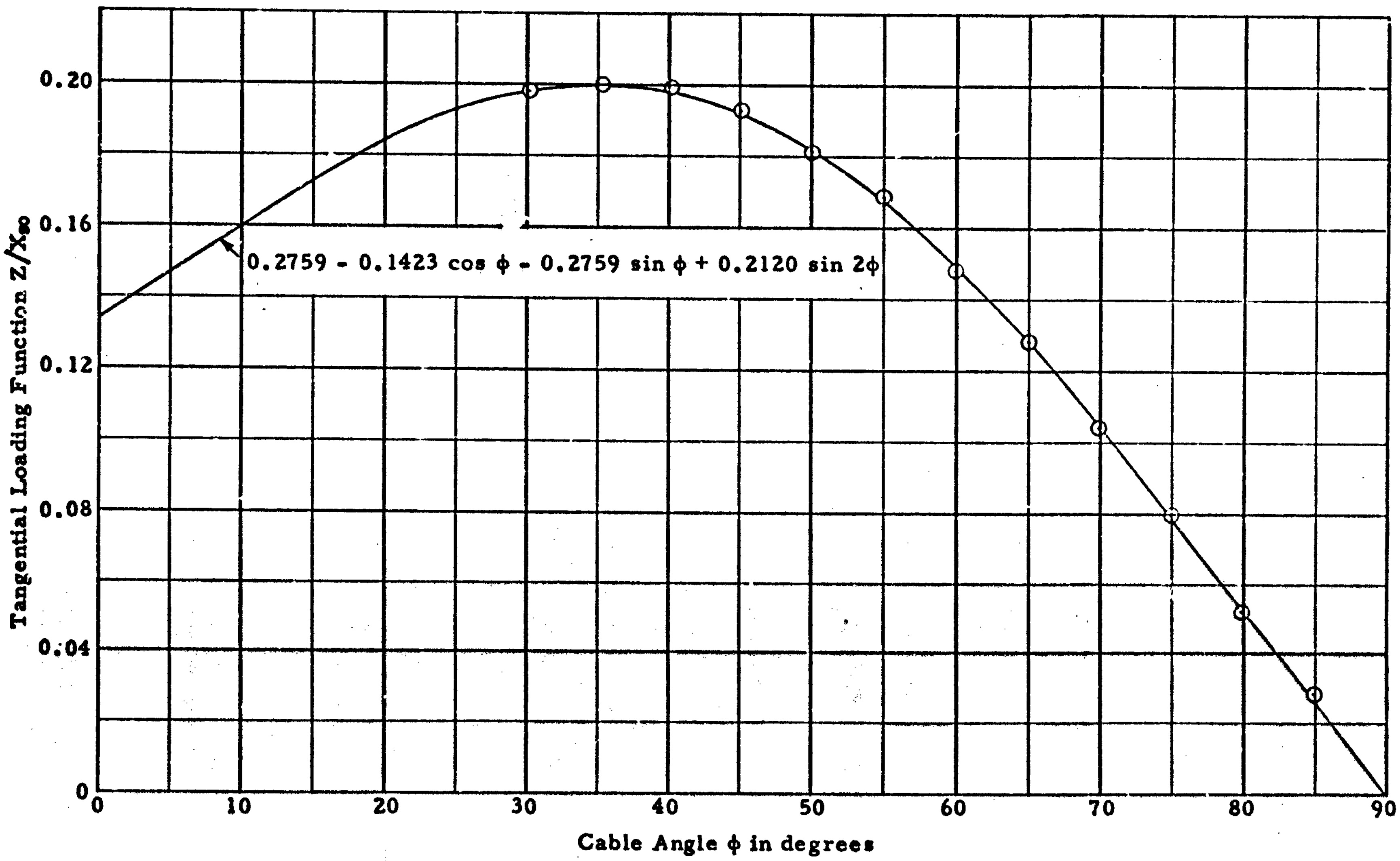

Figure 6 - Tangential Loading Function Versus Cable Angle

TABLE 2

Values of Normal and Tangential Loading Function

Cable Angle, degrees	Normal, X/X_{90}				Tangential, Z/X_{90}			
	Speed, knots				Speed, knots			
	2	4	6	8	2	4	6	8
30.17	0.265	0.267	0.263	0.261	0.218	0.203	0.191	0.181
35.30	0.312	0.327	0.326	0.326	0.223	0.205	0.192	0.180
40.25	0.390	0.395	0.396	0.393	0.223	0.205	0.191	0.177
45.10	0.450	0.464	0.463	0.465	0.218	0.201	0.188	0.166
50.03	0.533	0.532	0.527	0.527	0.208	0.194	0.172	0.151
54.97	0.591	0.597	0.600	0.600	0.197	0.182	0.153	0.143
59.95	0.669	0.682	0.682	0.685	0.180	0.167	0.131	0.112
64.98	0.759	0.762	0.761	0.758	0.159	0.146	0.111	0.095
69.88	0.830	0.837	0.833	0.832	0.133	0.122	0.089	0.073
74.92	0.878	0.889	0.886	0.887	0.105	0.096	0.064	0.054
79.85	0.946	0.949	0.941	0.943	0.075	0.068	0.033	0.030
84.90	0.968	0.976	0.976	0.974	0.043	0.039	0.022	0.009
90.00	1.000	1.000	1.000	1.000	0	0	0	0

Mathematical expressions for the loading functions were obtained using a computer program developed by the Applied Mathematics Laboratory (AML). This AML program, designated as BVPDE-3, determines a least-squares fit to the data for a prescribed trigonometric series. Neglecting any Reynolds number effect, the mathematical expressions as computed by the AML program for the B-5 fairing are as follows:

Normal loading function

$$-1.0640 + 1.2633\cos\phi + 1.8647\sin\phi - 0.1993\cos 2\phi - 0.6926\sin 2\phi$$

Tangential loading function

$$0.2759 - 0.1423\cos\phi - 0.2759\sin\phi + 0.2120\sin 2\phi$$

These expressions are also plotted in Figures 5 and 6.

DRAG COEFFICIENT

The drag coefficient C_R and corresponding Reynolds number R_d were calculated for each speed using the following expressions:

$$C_R = \frac{R}{\frac{1}{2} \rho d V^2}$$

and

$$R_d = \frac{Vd}{\nu}$$

where

d is the cable diameter,

R is the drag per unit length of cable when the cable is normal to the stream direction and is equal to the slope $\frac{\Delta X}{\Delta s}$ of the force-submergence plot at $\phi = 90$ degrees,

s is the distance along the cable (submergence),

V is the speed,

ρ is the mass density of water (1.9360 slugs/ ft^3 for these tests), and

ν is the kinematic viscosity of water.

Calculated drag coefficients are plotted as a function of Reynolds number in Figure 7. It should be noted that the drag coefficients of the B-5 fairing are considerably less than those of another trailing fairing reported in Reference 9.

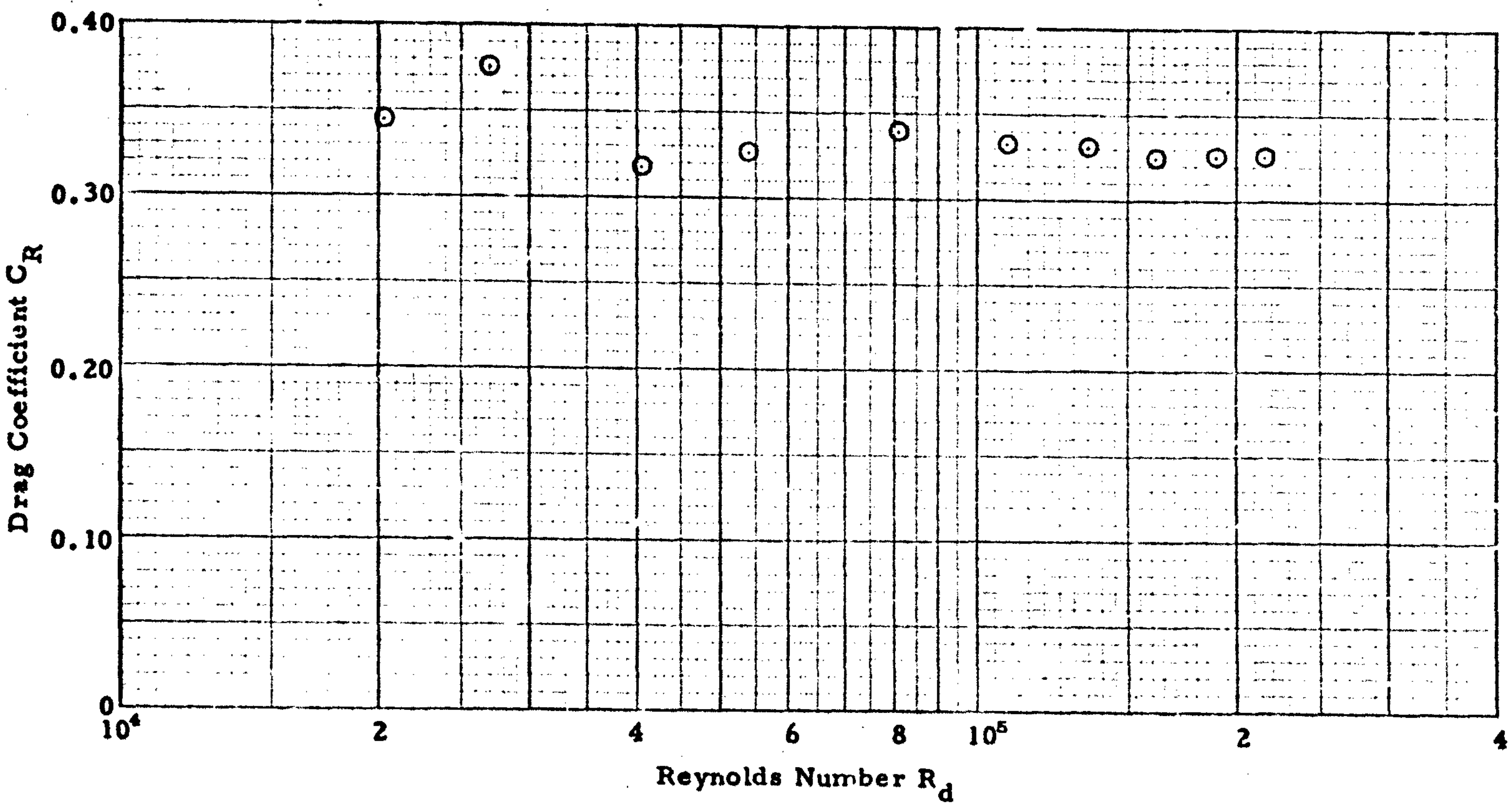

Figure 7 - Drag Coefficient Versus Reynolds Number

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